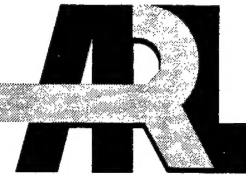


ARMY RESEARCH LABORATORY



Microwave Circuit Simulator for MATLAB

Romeo D. del Rosario and Daniel C. Judy

ARL-TN-184

March 2002

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Army Research Laboratory

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Abstract

This technical note describes a microwave circuit simulator implemented in the technical computing language, MATLAB. The simulator takes an input circuit with a known admittance matrix, performs a node swap that puts the external nodes (ports) at the upper left hand of an equivalent admittance matrix, then reduces the matrix (regardless of size) to include only the external nodes using Householder's method. The resulting 2×2 admittance matrix provides all the information to uniquely define the circuit from its external ports and facilitates straightforward calculation of Z-parameters, S-parameters, etc. (In our case, the reduced matrix is 2×2 ; however, the method applies to multiple port devices as well.) Although it can be used by itself, the simulator is designed with a bent toward empirical (circuit based) transistor models and may be incorporated into small and large signal transistor models.

1. Introduction

This technical note describes a microwave circuit simulator implemented in the technical computing language, MATLAB. The simulator takes an input circuit with a known admittance matrix, performs a node swap that puts the external nodes (ports) at the upper left hand of an equivalent admittance matrix, then reduces the matrix (regardless of size) to include only the external nodes using Householder's method. The resulting 2×2 admittance matrix provides all the information to uniquely define the circuit from its external ports and facilitates straightforward calculation of Z-parameters, S-parameters, etc. (In our case, the reduced matrix is 2×2 ; however, the method applies to multiple port devices as well.) Although it can be used by itself, the simulator is designed with a bent toward empirical (circuit based) transistor models and may be incorporated into small and large signal transistor models.

2. Algorithms

2.1 Simulator

1. Design input (circuit)
2. Assign node numbers
3. Determine self admittances (diagonals of $[Y]$)
4. Determine trans admittances (off-diagonal elements of $[Y]$)
5. Frequency plan
6. Calculate $[Y(f)]$ for each frequency point
7. Apply node switch algorithm
8. Apply Householder's theorem to obtain reduced admittance matrix $[Y_{red}]$
9. Calculate other parameters e.g. $[S]$, $[Z]$, etc. from $[Y_{red}]$
10. Repeat for every frequency point

2.2 Node Switch Algorithm

It is desirable to reduce, when possible, the amount of data involved in performing a circuit simulation. One approach is to reduce the admittance matrices so that only the external nodes (ports) are described. Before this can be accomplished, however, it is necessary to reconfigure the matrix, placing the external nodes in the upper left corner:

1. Assume that K and L are the nodes to be switched.
2. Start loop for rows.
3. Start loop for columns.
4. If row K (K or L) AND column K (K or L), then $Y'_{row,col} = Y_{row,col}$.
5. If row K (K or L) AND column = K then $Y'_{row,col} = Y'_{row,L}$.
6. If row K (K or L) AND column = L , then $Y'_{row,col} = Y'_{row,K}$.
7. If row = K AND column = L , then $Y'_{row,col} = Y_{L,K}$.
8. If row = K AND column = K , then $Y'_{row,col} = Y'_{L,L}$.
9. If row = K AND column K (K or L), then $Y'_{row,col} = Y'_{L,col}$.
10. If row = L AND column K (K or L), then $Y'_{row,col} = Y'_{K,col}$.
11. If row = L AND column = K , then $Y'_{row,col} = Y'_{K,L}$.

12. If row = L AND column = L, then $Y'_{\text{row,col}} = Y'_{K,K}$.

13. Repeat for every frequency point.

Example

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

becomes

$$\begin{bmatrix} I_1 \\ I_3 \\ I_2 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{13} & Y_{12} \\ Y_{31} & Y_{33} & Y_{32} \\ Y_{21} & Y_{23} & Y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_3 \\ V_2 \end{bmatrix}$$

2.3 Application of Householder's Method

Assuming that a node swap has been performed in order to place the external nodes at the upper left corner of the total admittance matrix, Y_{total} , we can now reduce this matrix, regardless of initial size, to a considerably smaller one that entails only the external nodes (1 and 2 in this example for a two-port circuit.) This is achieved by virtue of Householder's method so that a matrix can be broken into submatrices as follows [3]:

$$[Y_{\text{total}}] = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} & Y_{15} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} & Y_{25} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} & Y_{35} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} & Y_{45} \\ Y_{51} & Y_{52} & Y_{53} & Y_{54} & Y_{55} \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{bmatrix} & \begin{bmatrix} Y_{13} & Y_{14} & Y_{15} \\ Y_{23} & Y_{24} & Y_{25} \end{bmatrix} \\ \begin{bmatrix} Y_{31} & Y_{32} \\ Y_{41} & Y_{42} \\ Y_{51} & Y_{52} \end{bmatrix} & \begin{bmatrix} Y_{33} & Y_{34} & Y_{35} \\ Y_{43} & Y_{44} & Y_{45} \\ Y_{53} & Y_{54} & Y_{55} \end{bmatrix} \end{bmatrix} = \begin{bmatrix} Y_{ee} & Y_{ei} \\ Y_{ie} & Y_{ii} \end{bmatrix}$$

where subscripts "e" and "i" denote external and internal, respectively.

Likewise, Ohm's Law in the matrix form can be reduced.

$$I = \begin{bmatrix} I_e \\ I_i \end{bmatrix} = \begin{bmatrix} Y_{ee} & Y_{ei} \\ Y_{ie} & Y_{ii} \end{bmatrix} \begin{bmatrix} V_e \\ V_i \end{bmatrix}$$

We recall that an individual element of the admittance matrix, Y_{KL} can be calculated by shorting all nodes $\neq K$ or L and applying an internal current voltage, V_i , and by observing the current I_i . However, assuming a passive device, all the internal currents are zero and

$$I_e = Y_{ee}V_e + Y_{ie}V_i$$

$$0 = Y_{ie}V_e + Y_{ii}V_i$$

$$V_i = -Y_{ii}^{-1}Y_{ie}V_e$$

$$\therefore I_e = \left(Y_{ee} - Y_{ie}Y_{ii}^{-1}Y_{ie} \right) V_e$$

$$Y_{reduced} = Y_{ee} - Y_{ie}Y_{ii}^{-1}Y_{ie}$$

3. Results and Comparison to ANSOFT Serenade

Figure 1. Calculated S_{21} Ansoft (circles) and MATLAB (solid).

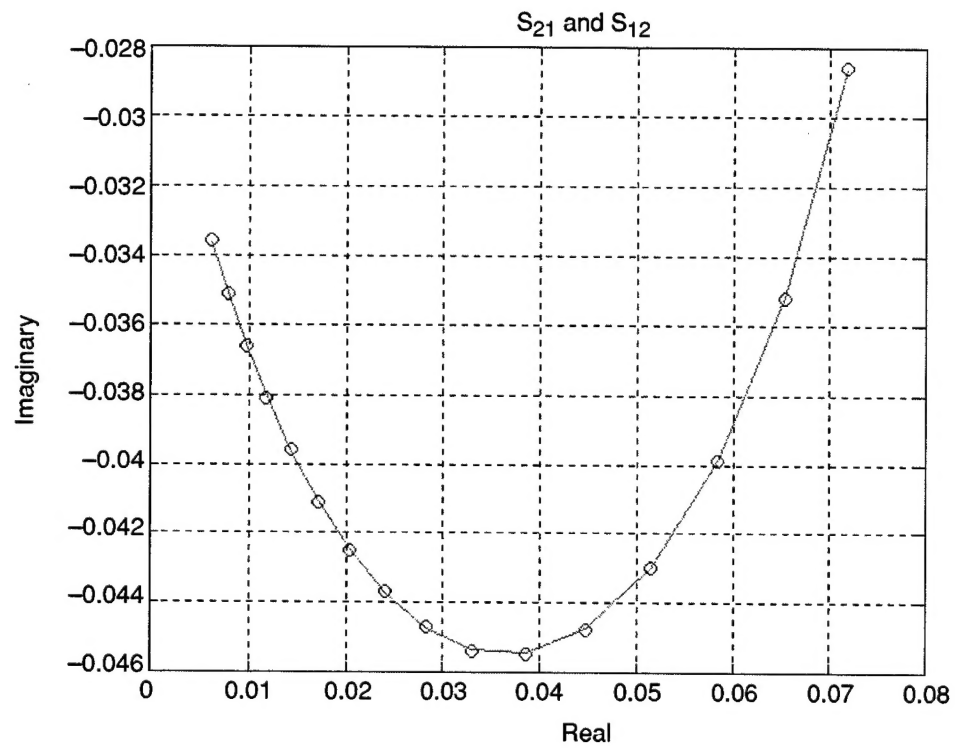


Figure 2. Calculated S_{11} Ansoft (circles) and MATLAB (solid).

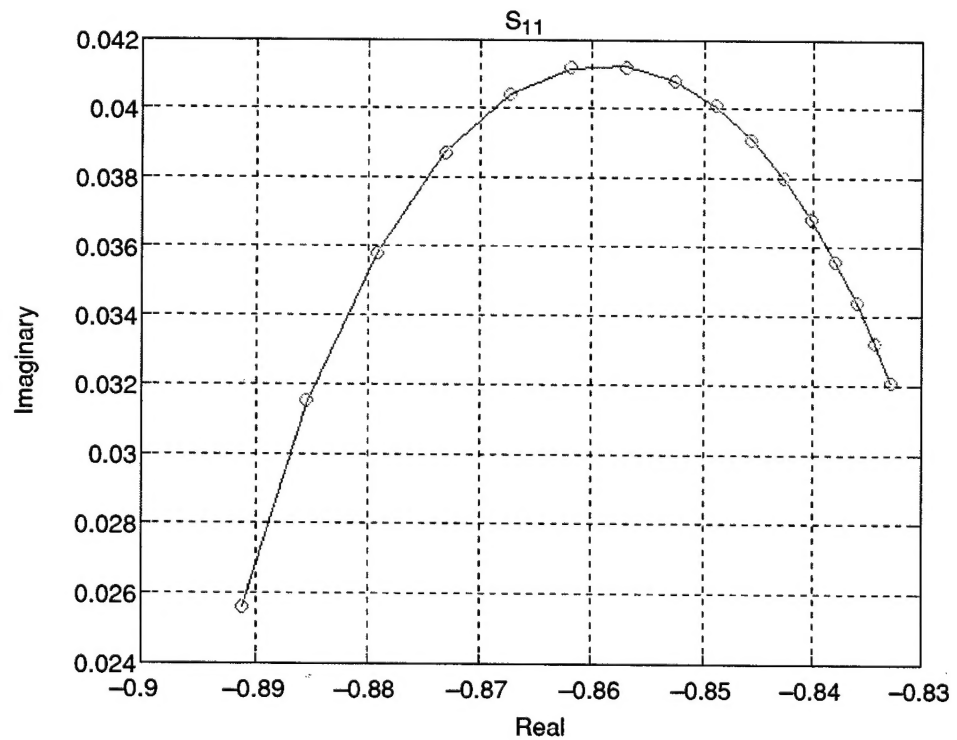


Figure 3. Calculated S_{22} Ansoft (circles) and MATLAB (solid).

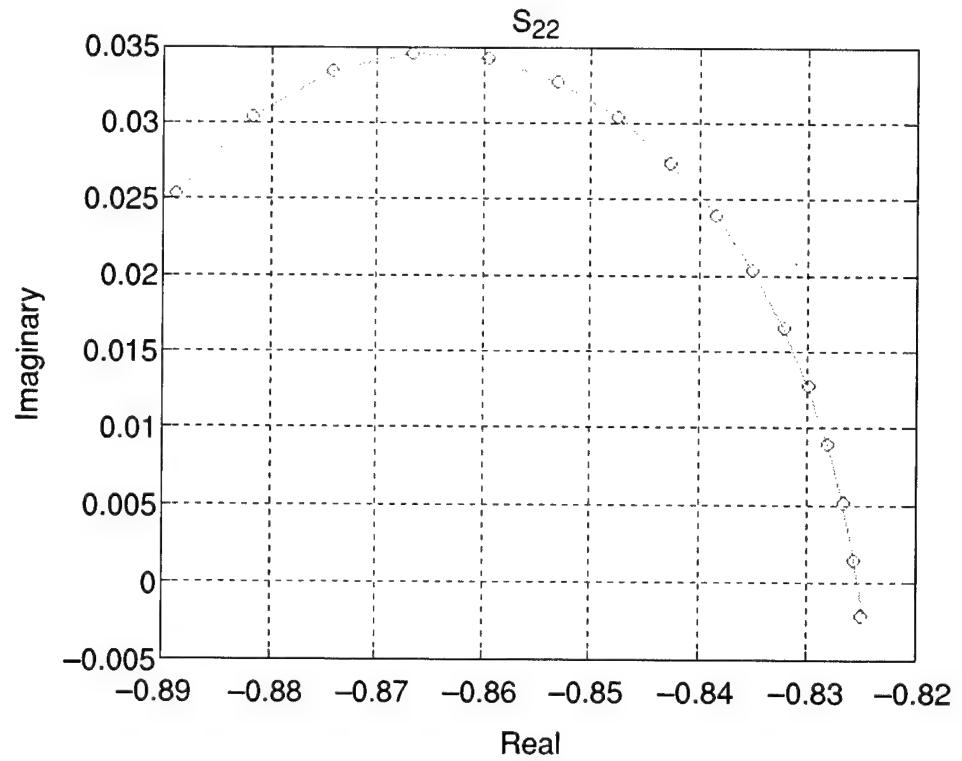
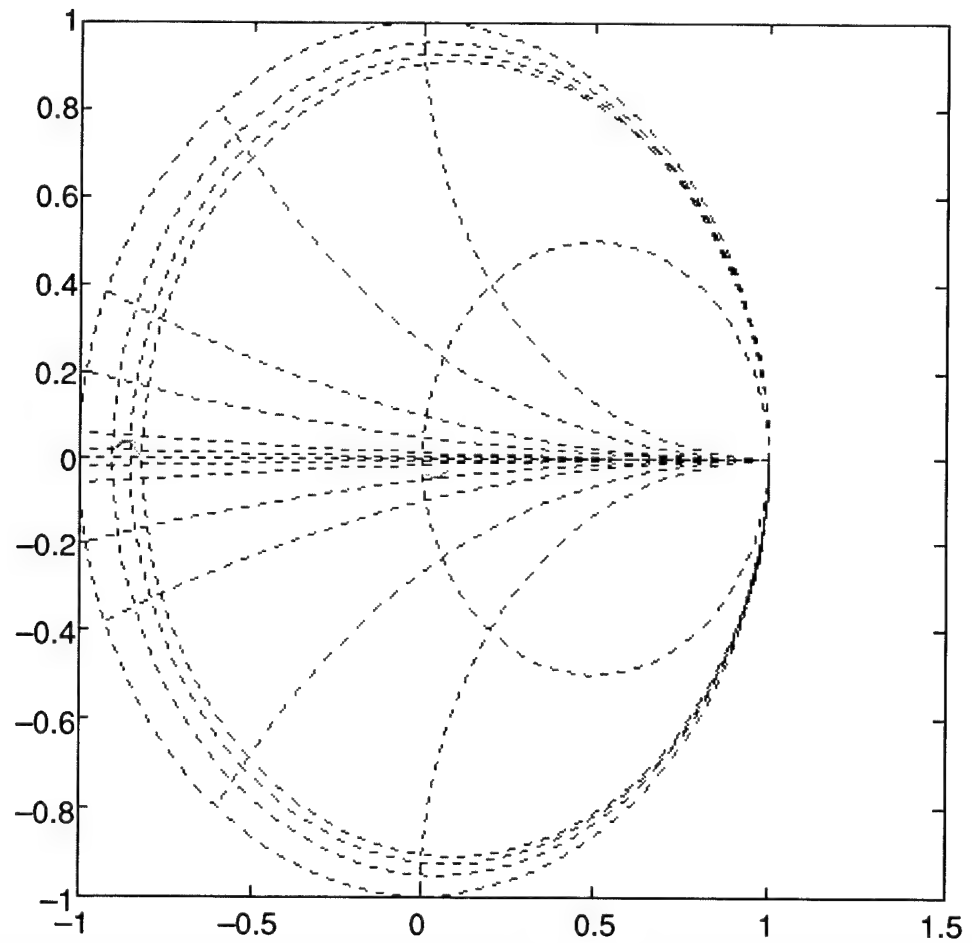


Figure 4. Locations of $[S]$ on unit Smith Chart.



Listing of Code

```
%rspace.m
% swap of nodes k,l e.g. k=2, l=5
% starting w/known Y(n,m)

Zo=50;pts=51; TRUE=1; % CONSTANTS
Y=[-2-j*.0398 j*.0398 0; j*.0398 1-j*.0105 -1; 0 -1 1.2];
Rg=0; Rx=0; Rd=0; Lg=0; Ld=0;
[n,m]=size(Y); k=2; L=3;

for FR=1:pts
    w=2*pi*1e9*FR; %m=1/w;
    ww(FR)=w;
    ymod(1,1,FR)=2+(1/(w*i*1e-9));    ymod(1,2,FR)=-1./j*w*1e-9;    ymod(1,3,FR)=0;
    ymod(2,1,FR)=-1./j*w*1e-9;    ymod(2,2,FR)=(j*w*2e-12)+1-(1./j*w*1e-9);    ymod(2,3,FR)=-1;
    ymod(3,1,FR)=0;    ymod(3,2,FR)=-1;    ymod(3,3,FR)=1.2;
end

for row=1:n
    for column=1:m
        for FR=1:pts
            switch TRUE
                case ((row==k)&(row==L)) & ((column==k)&(column==L)), ymodP(row,column,FR)=ymod(row,column,FR);
                case ((row==k)&(row==L)) & column==k, ymodP(row,column,FR)=ymod(row,L,FR);
                case ((row==k)&(row==L)) & column==L, ymodP(row,column,FR)=ymod(row,k,FR);
                case row==k & column==L, ymodP(row,column,FR)=ymod(L,k,FR);
                case row==k & column==k, ymodP(row,column,FR)=ymod(L,L,FR);
                case row==k & ((column==k)&(column==L)), ymodP(row,column,FR)=ymod(L,column,FR);
                case row==L & ((column==k)&(column==L)), ymodP(row,column,FR)=ymod(k,column,FR);
                case row==L & column==k, ymodP(row,column,FR)=ymod(k,L,FR);
                case row==L & column==L, ymodP(row,column,FR)=ymod(k,k,FR);
            end
        end
    end
end

for FR=1:pts
    % reduce Y-matrix to just the external nodes (ports) using Householder's Theorem
    nn=2; mm=2;
    yee(:,FR)=ymodP(1,nn,1,m,FR);
    yei(:,FR)=ymodP(1,nn,mm+1,m,FR);
    yie(:,FR)=ymodP(nn+1,n,1,m,FR);
    yui(:,FR)=ymodP(nn+1,n,mm+1,m,FR);
    yred(:,FR)=yee(:,FR)-(yei(:,FR)*inv(yui(:,FR))*yie(:,FR));

    %%%%%%%%%% convert to intrinsic, z-parameters of model %%%%%%%%%%
    det_y(FR)=yred(1,1,FR)*yred(2,2,FR)-yred(1,2,FR)*yred(2,1,FR);
    zmod(1,1,FR)=yred(2,2,FR)/det_y(FR);    zmod(1,2,FR)=-yred(1,2,FR)/det_y(FR);
    zmod(2,1,FR)=-yred(2,1,FR)/det_y(FR);    zmod(2,2,FR)=yred(1,1,FR)/det_y(FR);
end
```

Listing of Code (cont'd)

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% 7. Calculate extrinsic, Z, parameters by adding parasitics back to zmod
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Zmod(1,1,FR)=zmod(1,1,FR) + (Rg+Rs) + j.*ww(FR).*(Lg + Ls);
Zmod(1,2,FR)=zmod(1,2,FR) + Rs - j.*ww(FR).*Ls;
Zmod(2,1,FR)=zmod(2,1,FR) + Rs - j.*ww(FR).*Ls;
Zmod(2,2,FR)=zmod(2,2,FR) + (Rd+Rs) + j.*ww(FR).*(Ld + Ls);

ZmodP(1,1,FR)=Zmod(1,1,FR)./Zo; ZmodP(1,2,FR)=Zmod(1,2,FR)./Zo;
ZmodP(2,1,FR)=Zmod(2,1,FR)./Zo; ZmodP(2,2,FR)=Zmod(2,2,FR)./Zo;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% 8. Convert Zmod to S_mod
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

delt1(FR)=(ZmodP(1,1,FR)+1).*(ZmodP(2,2,FR)+1) - (ZmodP(1,2,FR).*ZmodP(2,1,FR));
Smod(1,1,FR)= ( (ZmodP(1,1,FR)-1).*(ZmodP(2,2,FR)+1) - (ZmodP(1,2,FR).*ZmodP(2,1,FR)) ) ./delt1(FR);
Smod(1,2,FR)=2.*ZmodP(1,2,FR)./delt1(FR);
Smod(2,1,FR)=2.*ZmodP(2,1,FR)./delt1(FR);
Smod(2,2,FR)=((ZmodP(1,1,FR)-1).*(ZmodP(2,2,FR)-1) - (ZmodP(1,2,FR)).*(ZmodP(2,1,FR)))/delt1(FR);

Smod11(FR)=Smod(1,1,FR); Smod12(FR)=Smod(1,2,FR); Smod21(FR)=Smod(2,1,FR); Smod22(FR)=Smod(2,2,FR);

end

```

Conclusion/Recommendations

Improvements that could be made include a text-based input interface similar to a SPICE net list or even a graphical user input. As implemented, it can easily be modified to be included in larger MATLAB programs, e.g., to simulate an empirical (circuit based) model of a transistor in order to compare it with measured data.

References

- [1] Microwave Transistor Amplifiers, Gonzalez.
- [2] Microwave & RF Circuits: Analysis, Design, Fabrication & Measurement, Notes from M.L. Edwards (1995).
- [3] Advanced Engineering Mathematics, 7th Edition, Kreyszig.

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE March 2002		3. REPORT TYPE AND DATES COVERED Progress, Aug 01 to Sept 01
4. TITLE AND SUBTITLE Microwave Circuit Simulator for MATLAB			5. FUNDING NUMBERS DA PR: AH94 PE: 62705A	
6. AUTHOR(S) Romeo D. del Rosario and Daniel C. Judy				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Attn: AMSRL-SE-RE email: romeo@arl.army.mil 2800 Powder Mill Road Adelphi, MD 20783-1197			8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TN-184	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1197			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES ARL PR: 2NE6K1 AMS code: 622705.H9411				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This technical note describes a microwave circuit simulator implemented in the technical computing language, MATLAB. The simulator takes an input circuit with a known admittance matrix, performs a node swap that puts the external nodes (ports) at the upper left hand of an equivalent admittance matrix, then reduces the matrix (regardless of size) to include only the external nodes using Householder's method. The resulting 2×2 admittance matrix provides all the information to uniquely define the circuit from its external ports and facilitates straightforward calculation of Z-parameters, S-parameters, etc. (In our case, the reduced matrix is 2×2 ; however, the method applies to multiple port devices as well.) Although it can be used by itself, the simulator is designed with a bent toward empirical (circuit based) transistor models and may be incorporated into small and large signal transistor models.				
14. SUBJECT TERMS microwave circuit simulation			15. NUMBER OF PAGES 16	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT UL	